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ANALYSIS RESPONSES OF JUVENILE *SIGANUS VERMICULATUS* TO ARTIFICIAL BIOACOUSTICS STIMULI (LABORATORY SCALE)

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ABSTRACT

Siganus vermiculatus is a rabbitfish species that is commonly consumed and has important economic value in Indonesia. Traps are fishing gears commonly used to catch this group of fish. One of the main disadvantages of trap fishing is its low size selectivity, as traps function not only as capture devices but also provide opportunities to serve as shelters. *S. vermiculatus* possesses sensory organs including the inner ear, lateral line, and swim bladder, indicating sensitivity to acoustic stimuli. Therefore, this study was conducted to investigate the effects of artificial bioacoustics stimuli on the behavior of juvenile *S. vermiculatus*. The study was conducted on a laboratory scale at the Capture Fisheries Workshop, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro. The treatment used artificial bioacoustics stimuli in the form of continued sound. Data were collected through observation, literature review, and documentation. The data were subsequently analyzed based on the occurrence zones and the number of fish responses. The results showed that the four *S. vermiculatus* individuals tended to concentrate in Zone 3, while several treatments showed one fish located in Zone 0. The highest number of responses by one *S. vermiculatus* individual to sudden sound was observed at a frequency of 200 Hz.

KEYWORDS: fish acoustic stimulus; low-frequency sound; juvenile *Siganus vermiculatus*

1. INTRODUCTION

Siganus vermiculatus is a fish species belonging to the family Siganidae that occurs in Indonesia and has important economic value (Suardi et al., 2019). The sustainability of

Siganus sp. fisheries in Indonesia faces several challenges in the field. The use of passive fishing gear such as traps, which are widely operated to catch Siganus sp., may pose a threat when juvenile Siganus sp. are frequently captured. Trap-type fishing gears, such as trap with line and button trap, are widely used by fishers to catch Siganus sp. (Syadli et al., 2022). Small-sized *Siganus sutor* that had not yet reached the appropriate catch size were significantly captured by artisanal traps, as indicated by the high proportion of catches below the size at first maturity. As many as 56% of the artisanal trap catch were below the size at first maturity and were therefore biologically categorized as undersized and unsuitable for capture (Gomes et al., 2014). The continued use of passive fishing gear that captures juvenile Siganus sp. as bycatch indicates low gear selectivity and is inconsistent with the principles of the Code of Conduct for Responsible Fisheries, which emphasizes minimizing bycatch in fishing activities (FAO, 1995).

To avoid such occurrences, artificial bioacoustics stimuli can be used to distract and deter *S. vermiculatus* from passive fishing gear such as traps. *Siganus* sp. was known to be sensitive to disturbances such as sound or vibrations in their surroundings (Ghufran and Kordi, 2005). Artificial bioacoustics stimuli are known to influence fish behavior (Popper and Hawkins, 2019). Various studies have demonstrated that acoustic stimuli can affect fish behavior. Zhang et al. (2024) reported that Siganus guttatus has high sensitivity to low frequencies, particularly 200 Hz, which affects swimming patterns. Vetter et al. (2015) showed that complex outboard engine sounds can trigger avoidance responses, whereas Pieniazek et al. (2020) found that noise exposure caused erratic swimming and reduced feeding activity. In addition, Calger et al. (2012) and Kenyon et al. (1998) explained that fish hearing ability is influenced by sound characteristics and environmental conditions. Nevertheless, information on the application of artificial bioacoustics stimuli to deter juvenile *S. vermiculatus* remains limited.

Further research is therefore needed to investigate the effects of artificial bioacoustics stimuli on juvenile *S. vermiculatus*, particularly within the low-frequency range known to influence Siganus sp. behavior (Zhang et al., 2024). Accordingly, this study aimed to test the effects of artificial bioacoustics stimuli at frequencies of 100, 200, 300, 400, and 500 Hz on the behavior of juvenile *S. vermiculatus*. The effects on other fish species that may become targets of trap fisheries were not considered in this study and therefore require further investigation.

2. METHODOLOGY

2.1 Time and Location of the Study

The study was conducted from June 2025 to March 2026 on a laboratory scale at the Workshop Building of the Department of Capture Fisheries, Faculty of Fisheries and Marine Sciences, Universitas Diponegoro.

2.2 Artificial Bioacoustics Transmitter

The device used in this study was an innovative transmitter capable of emitting sounds with frequencies ranging from 10 Hz to 20 kHz. The device was integrated with a laptop for performance monitoring and manual control of sound intensity (Figure 1). Before the artificial bioacoustics transmitter was tested, sound intensity was first measured using a decibel meter (Table 1) and an oscilloscope (Table 2).

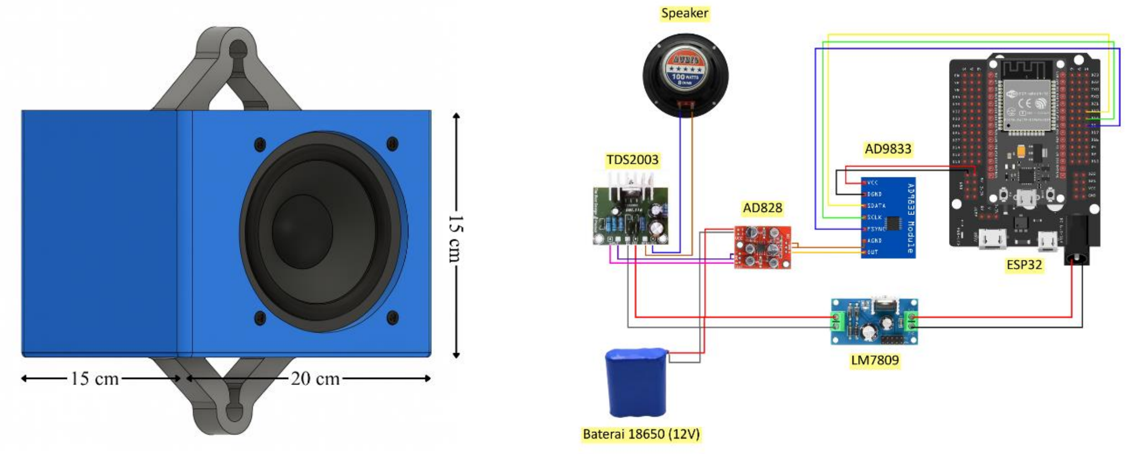

Figure 1. Design and Mechanism of the Artificial Bioacoustics Transmitter.

Table 1. Sound Measurements Using a Decibel Meter.

Frequency (Hz)	Distance (cm)	Replication			Mean (dB)
		1	2	3	
100	0	108.0	107.7	107.7	107.6
200	0	108.6	109.0	108.9	108.8
300	0	109.0	109.8	109.2	109.3
400	0	109.5	109.8	109.7	109.6
500	0	109.7	109.5	109.7	109.6

Table 2. Sound Measurements Using an Oscilloscope.

Frequency (Hz)	Result (Hz)
100	100.021
200	199.975
300	299.991
400	400.038
500	500.033

2.3 Experimental Animals

Four *S. vermiculatus* individuals were used in the study, with a mean total length (TL) of 15 cm (juveniles). The length range of juvenile *S. vermiculatus* is approximately 14–19 cm, whereas adult rabbitfish generally range from 20–45 cm in body length (Suherman, 2021). The *S. vermiculatus* individuals were obtained from fishers using trap fishing gear in the waters of Jepara, Indonesia. The *S. vermiculatus* individuals were acclimatized for 24 h to adapt to aquarium conditions and were fed seaweed of the genus *Gracilaria* sp., which was subsequently used as bait to attract *S. vermiculatus* toward the sound source.

2.4. Experimental Procedure

This study used two types of artificial bioacoustics treatments: sudden sound and continuous sound. The frequencies tested were 100, 200, 300, 400, and 500 Hz. The sudden sound treatment was applied for 10 s with a 120-s interval, whereas the continuous sound treatment was applied for 300 s with a 300-s interval at each tested frequency. Intervals between treatments were provided to prevent habituation in the fish, which could lead to reduced behavioral responses due to adaptation to continuous acoustic exposure (Neo et al., 2015). Each type and frequency of artificial bioacoustics treatment was replicated nine times.

Experiments on the effects of artificial bioacoustics distraction on *S. vermiculatus* behavior were conducted in an aquarium measuring 80 cm in length, 40 cm in width, and 45 cm in height, with an observation area extending 60 cm (Figure 2). The aquarium was filled with seawater to a depth of 40 cm, with salinity of 33–34 pt, a temperature of 25–30°C, and pH 8. These water conditions are considered optimal for the survival of rabbitfish (Suci et al., 2020). The observation area was divided into several zones to facilitate the classification of juvenile *S. vermiculatus* responses after each treatment. The observation area was divided into four zones: Zone 0 (fish located below/behind the device), Zone 1 (0–20 cm), Zone 2 (20–40 cm), and Zone 3 (40–60 cm) from the sound source (Figure 3).

Rabbitfish are diurnal fish (Paris and Kantun, 2023); therefore, the treatments were conducted in the morning, which is the active feeding period for rabbitfish, so that the fish would approach the seaweed serving as bait or an attractant. *Gracilaria sp.* seaweed was suspended and submerged according to the position of the artificial bioacoustics ransmitter.

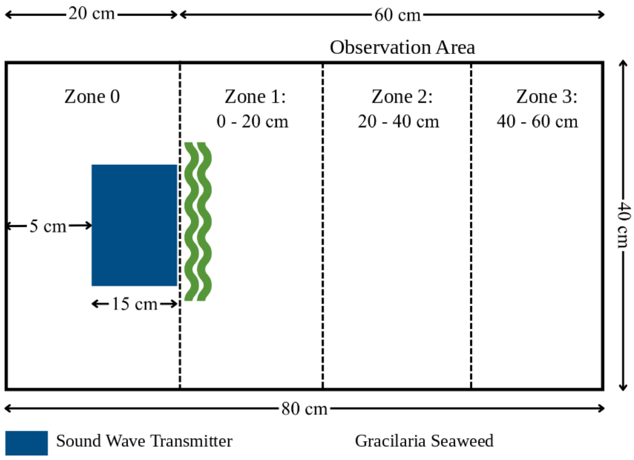

Figure 2. Top-View Visualization of the Observation Area.

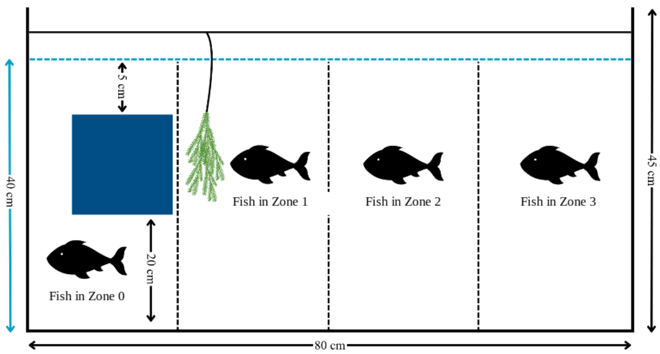

Figure 3. Side-View Visualization of the Observation Area.

2.5 Analysis of the Occurrence Radius of *S. vermiculatus*

The analysis of the occurrence radius of juvenile *S. vermiculatus* was conducted to obtain data on fish position when exposed to artificial bioacoustics distraction. The position of *S. vermiculatus* was observed for each treatment. Fish located in Zone 0 were categorized as being beneath the artificial bioacoustics transmitter, Zone 1 as near, Zone 2 as intermediate, and Zone 3 as far from the sound source.

The analysis of the number of juvenile *S. vermiculatus* responses was conducted to obtain data on the number and type of responses shown by the fish over nine repetitions. Fish swimming away from the sound source were assumed to be distracted.

2.6 Statistical Analysis

Cochran's Q test was used to assess whether differences in sound type and frequency level affected the presence or absence of responses in juvenile *S. vermiculatus* (Value 1: response present; Value 0: no response). H_0 indicated that there was no difference in juvenile *S. vermiculatus* responses among frequencies, whereas H_1 indicated that there was a difference in responses at least at one sound frequency. With a significance level of $\alpha = 5\%$, the testing criteria were defined as follows: if the probability (sig) > 0.05, H_0 was accepted, and if the probability (sig) < 0.05, H_0 was rejected.

3. RESULT AND DISCUSSION

3.1 Occurrence Radius of *S. vermiculatus*

Observations of the occurrence zones of juvenile *S. vermiculatus* when the artificial bioacoustics transmitter was activated under the sudden sound treatment (Table 3) and continuous sound treatment (Table 4), with nine repetitions at frequencies of 100, 200, 300, 400, and 500 Hz, showed that the four fish tended to remain in Zone 3, corresponding to a distance of 40–60 cm from the sound source. Several treatments also showed one fish located in Zone 0, below or behind the artificial bioacoustics transmitter, while the other three fish remained motionless in the corner at the bottom of the aquarium (Zone 3).

Table 3. Occurrence of *Siganus vermiculatus* under the Sudden Sound Treatment.

Replication No.	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz
	Zone	Zone	Zone	Zone	Zone
1	3	3	3	3	3
2	3	3	3	3	3
3	3	3	3	3	3
4	3	3	3	3	3
5	0	0	0	3	3
6	3	3	3	3	3
7	0	3	3	3	3
8	3	0	3	3	3
9	0	3	3	0	0

Table 4. Occurrence of *Siganus vermiculatus* under the Sudden Sound Treatment.

Replication No.	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz
	Zone	Zone	Zone	Zone	Zone
1	3	3	3	3	3
2	3	3	3	3	3
3	3	3	3	3	3
4	3	3	3	3	3
5	3	0	3	3	3

6	3	3	3	3	3
7	3	3	3	3	3
8	3	3	3	0	3
9	3	3	3	3	3

3.2 Number of *S. vermiculatus* Responses

Observations of *S. vermiculatus* responses showed that only one of the four fish was actively responsive. For the sudden sound treatment (Figure 4), the juvenile *S. vermiculatus* individual responded 5 times at 100 Hz, 7 times at 200 Hz, 4 times at 300 Hz, 2 times at 400 Hz, and 2 times at 500 Hz. Under the continuous sound treatment (Figure 5), the same juvenile *S. vermiculatus* individual responded 3 times at 100 Hz, 5 times at 200 Hz, 1 time at 300 Hz, and 1 time at 400 Hz, while at 500 Hz the fish did not respond to the artificial bioacoustics stimulus and remained motionless.

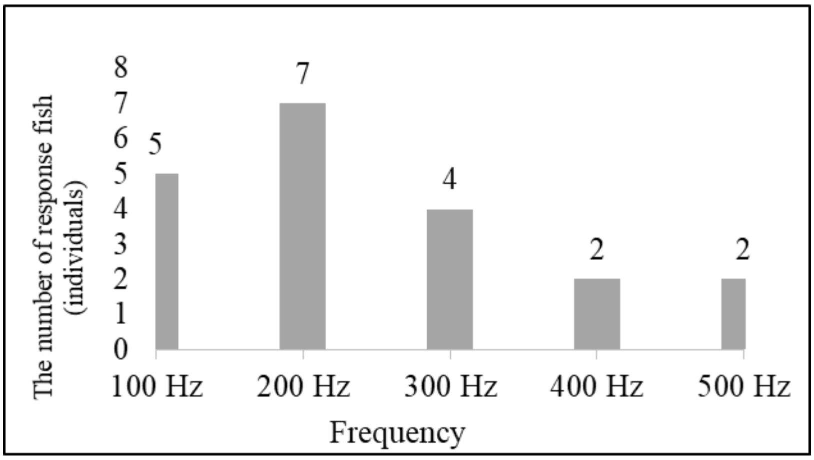

Figure 4. Number of Juvenile *S. vermiculatus* Responses under the Sudden Sound Treatment.

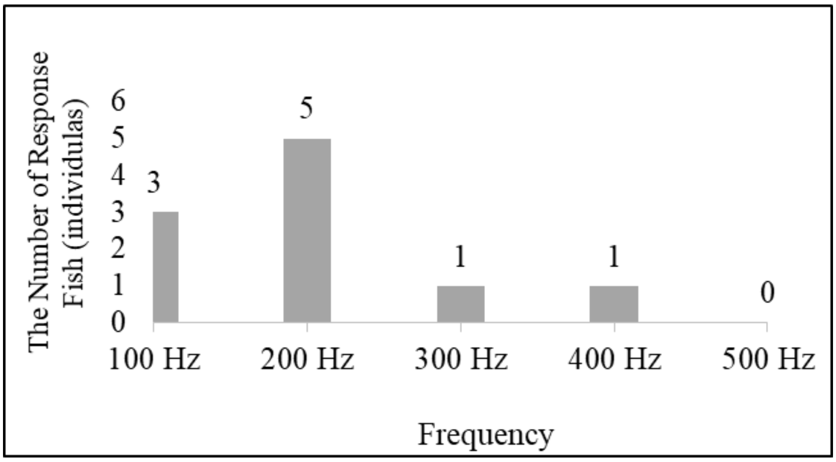

Figure 5. Number of Juvenile *S. vermiculatus* Responses under the Continuous Sound Treatment.

3.3 Statistical Analysis

The Cochran's Q test showed that the sudden sound treatment had a significance value of $p = 0.061$, which was greater than 0.05 (Table 6), indicating that this treatment did not have a statistically significant effect on the presence or absence of juvenile *Siganus vermiculatus* responses. In contrast, the continuous sound treatment produced a significance value of $p = 0.040$, which was lower than 0.05 (Table 8), indicating that this treatment had a statistically significant effect on the presence or absence of fish responses.

Table 5. Distribution of Juvenile *Siganus vermiculatus* Response Data at Each Frequency under the Sudden Sound Treatment.

Frequency (Hz)	Value	
	0	1
100	4	5
200	2	7
300	5	4
400	7	2
500	7	2

Table 6. Results of the Cochran's Q Test for the Sudden Sound Treatment.

Test Statistics	
N	9
Cochran's Q	9.000[a]
df	4
Asymp. Sig.	.061

Table 7. Distribution of Juvenile *Siganus vermiculatus* Response Data at Each Frequency under the Continuous Sound Treatment.

Frequency (Hz)	Value	
	0	1
100	6	3
200	4	5
300	8	1
400	8	1
500	9	0

Table 8. Results of the Cochran's Q Test for the Continuous Sound Treatment.

Test Statistics	
N	9
Cochran's Q	10.000[a]
df	4
Asymp. Sig.	.040

Fish possess sensory systems capable of detecting environmental stimuli such as sound and vibration, which can trigger adaptive behavioral responses that support survival (Popper and Hawkins, 2019). Such responses commonly include avoidance behavior, changes in swimming direction, and a tendency to seek areas that are safer from disturbance (Domenici and Hale, 2019). The predominance of juvenile *S. vermiculatus* at the far end of the aquarium in Zone 3 after both sudden sound and continuous sound treatments indicates a tendency to seek an area relatively protected from exposure to artificial bioacoustics stimuli. The corner of the aquarium (Zone 3) often has lower sound pressure than other areas. Another possible explanation is the presence of an aerator in the corner of the aquarium, which may have caused the fish to remain there. Aerators supply oxygen and can increase dissolved oxygen concentrations in water (Zahidah et al., 2015). Dissolved oxygen is a critical factor determining fish survival, growth, and metabolism; therefore, fish may select optimal and comfortable environmental conditions to reduce stress (Subagja et al., 2025).

It should be noted that the behavioral responses of juvenile *S. vermiculatus* were not evenly distributed. Of the four individuals observed, most responses were shown by only one fish that was actively responsive to the bioacoustics treatments. The other three individuals tended to remain motionless at the bottom of the aquarium and did not show significant changes. This may indicate passive behavior (freezing behavior), which commonly occurs in response to environmental stress or suboptimal adaptation to a new habitat (Egan et al., 2009). The highest response of juvenile *S. vermiculatus* to both sudden sound and continuous sound treatments occurred at 200 Hz, followed by 100, 300, 400, and 500 Hz. This finding is consistent with the previous study by Zhang et al. (2024), which reported that rabbitfish are highly sensitive to low-frequency sound, particularly 200 Hz. The responses shown by *S. vermiculatus* consisted of erratic responses, characterized by uncoordinated swimming with sudden changes in direction. Such behavior generally occurs when fish experience stress, threats, or environmental disturbances (Ben-Yami, 1987). Noise exposure can also reduce fish interest in feeding (Pieniazek et al., 2020).

Fish possess an internal auditory system containing hair cells that detect sound-induced vibrations in water. In general, most fish are more sensitive to low frequencies (<300 Hz), although they can still respond to sounds up to 1000 Hz (Hastings and Thomas, 2025). Differences in organismal responses to noise are influenced by exposure duration, intensity, and sound pattern, so the resulting effects may vary. Continuous noise, for example, can cause more persistent behavioral and physiological disturbances because organisms receive uninterrupted stimulation, which ultimately affects activity and movement patterns (Erbe et al., 2022). In addition, research on *Lutjanus argentimaculatus* has shown that low frequencies are more effective in eliciting fish responses and may even function as attractors (Fitri et al., 2010). Thus, the combination of continuous sound patterns and low-frequency stimuli can be understood as a key factor influencing the behavioral responses of juvenile patterned rabbitfish (*S.iganus vermiculatus*).

4. CONCLUSION

The occurrence radius of the four juvenile *S. vermiculatus* individuals tended to be concentrated in Zone 3. Several treatments also showed one fish located in Zone 0, whereas the other three fish remained motionless in the bottom corner of the aquarium (Zone 3). The highest number of juvenile *S. vermiculatus* responses under both sudden sound and continuous sound treatments occurred at 200 Hz, indicating that juvenile *S. vermiculatus* were distracted by low-frequency sound. The Cochran's Q test showed no significant difference in the presence or absence of juvenile *S. vermiculatus* responses under the sudden sound treatment. In contrast, the continuous sound treatment produced a significant difference in the presence or absence of fish responses.

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